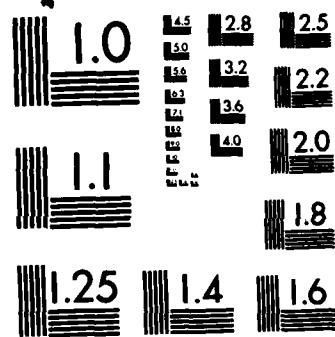


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DEFECT INSPECTION OF SOLID FUEL PROPELLANT CYLINDERS BY MEANS OF LASER
HOLOGRAPHIC TECHNIQUES

by

Jiang Linzhen, Lue Chichung, and Tsue Chenkuo

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Defect Inspection of Solid Fuel Propellant Cylinders
by means of Laser Holographic Techniques

Physics Teaching and Research Laboratory

Jiang Linzhen, Lue Chichung, and Tsue Chenkuo

(Translated by Shaoann Shon)

SUMMARY

 This paper describes the theory and practices of applying laser holographic interference techniques in the inspection of solid fuel propellant cylinders for defects such as shield debonds, internal cracks and voids. Experimental results obtained from the inspection and testing of solid fuel propellants with the application of heat stress and vacuum stress are reported. 

PREFACE

The bonding between a solid fuel propellant cylinder and its shield directly influences the performance of the propelling system. When defects such as debonds or voids exist between the solid fuel propellant and its shield, the inflamed cross-sectional area of the solid fuel propellant after its ignition will be expanded at the point of the defect, causing a sudden increase in pressure. This can lead to incidents such as a

localized burnt-through or even an explosion. For this reason, the non-destructive inspection is a very important step in the manufacturing process of the solid fuel propellants.

We have adopted a new method--laser holographic interference quantitative technique, for the inspection of the bonding mass between the solid fuel propellant cylinder and its shield, and for the detection of defects such as the cracks and voids in the solid fuel mass. This method not only can accurately detect large defects, it also gives better repeatability and reliability in the inspection and detection of small-grain flaws.

I Theory

Laser holographic interference methods can be grouped into roughly three categories: the single exposure method, the double exposure method, and the time-averaging method. Only two of the three methods were used in our experiments; the principal technique used being the double exposure method. The double exposure method is in essence the recording, on a holographic interference plate, of the holographic patterns produced by the object being inspected under two different conditions. The holographic image will then display two object waveforms. Even a very small difference in the phases of these waveforms will be manifested in the form of optical interference patterns. If we can apply proper stress loading

according to the material property of the object being inspected, then the interior grain flaws (such as debonds or voids) can be exhibited as the exterior deformation of the object. The optical interference pattern will then be deformed. Based on the deformation of the interference patterns, we can infer the extent of the interior defects.

The light intensity recorded on a holographic interference plate after double exposure can be formulated as:

$$\begin{aligned}
 I &= |O + R|^2 + |O_1 + R|^2 \\
 &= 2|R|^2 + |O|^2 + OR^* + O^*R + |O_1|^2 + O_1R^* + O_1^*R \\
 &= 2(R_0^2 + O_0^2) + O_0R_0e^{i(\varphi_0 - \varphi_R)} + O_0R_0e^{-i(\varphi_0 - \varphi_R)} + O_0R_0e^{i(\varphi_1 - \varphi_R)} + \\
 &\quad O_0R_0e^{-i(\varphi_1 - \varphi_R)}
 \end{aligned}$$

where O designates the optical waveform complex amplitude of the original object,

O_1 designates the optical waveform complex amplitude of the object deformed after the stress is applied,

R designates the reference waveform complex amplitude.

Under linear exposure conditions, the amplitude transmission coefficient T is directly proportional to I . When reimaged with the reference light source, the dispersed waveform will have a complex amplitude of

$$\begin{aligned}
 A = RT &= 2R_0(R_0^2 + O_0^2)e^{i\varphi_R} + O_0R_0e^{i\varphi_R} + O_0R_0e^{-i(\varphi_0 - 2\varphi_R)} \\
 &\quad + O_0R_0e^{i\varphi_1} + O_0R_0e^{-i(\varphi_1 - 2\varphi_R)}
 \end{aligned}$$

where the second term and the fourth term represent the reimaged

waveform of the original object and the object deformed under stress, respectively. We shall focus our consideration to these two terms only.

$$\text{Let } A_1 = O_1 R_1 e^{i\varphi_1} + O_2 R_2 e^{i\varphi_2} = O_1 R_1 (e^{i\varphi_1} + e^{i\varphi_2})$$

The corresponding light intensity

$$I_1 = A_1 A_1^* = 2O_1^2 R_1^2 (1 + \cos(\varphi_1 - \varphi_2))$$

It is observed that the intensity is a co-sine function, retaining the characteristics of optical interference from two light sources. The interference pattern is observable after the second exposure. There is a systematic pattern in this interference waveform. When interior defect exists in the object under test, the interference waveform will show deformation at the location of the defect.

II LIGHT PATHS AND THE EXPERIMENTAL SETUP

The light path of the experimental setup is as follows: The laser shown in the figure below is a 30mw Helium Neon laser. M_1 , M_2 , and M_3 are three reflecting mirrors. B_s is a beamsplitter, L_1 and L_2 are de-focussing devices, H is the holographic interference plate. Additional devices used in the experiments include: an ammeter, heat-stress loading equipment, vacuum-stress loading equipment, a shock absorbent table, and a dark room for photo developing.



Figure 1

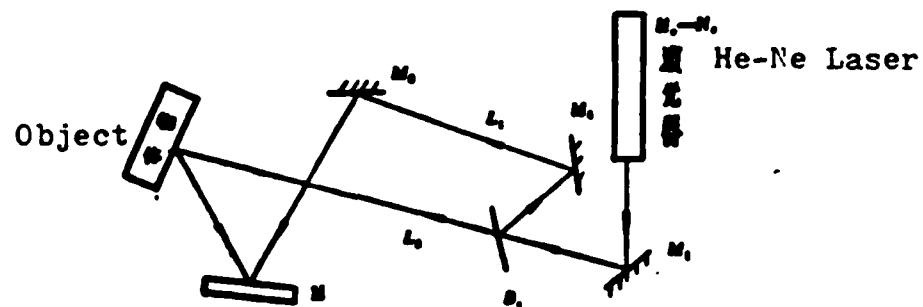


Figure Optical Path In Experimental Setup

III SAMPLE RESULTS

We inserted four different types of artificial defects into two sections of solid fuel propellant.

The first type is an open debonded area made by pricking the shield off the solid fuel cylinder with a bamboo prick. One such debond has a width of 2mm, length of 30mm; another has width 3mm, length 30mm.

The second type of manmade defect is effected by piercing the solid fuel cylinder radially from the shield surface

toward the center of the cylinder, thus producing an open cylinder of void. The measures of these voids are: diameter 6mm, length 46mm; diameter 3mm, length 33mm; diameter 1mm, length 27mm and 20mm.

The third type of inserted defect is made with a bonding material specially made by the Bonding Research Laboratory of our Institute. We inserted debonds on the sides and the ends of the solid fuel cylinder. The debonds are measured $\phi_{10}, \phi_5, \phi_4, \phi_3, \phi_2, \phi_{1.5}$ mm. We also introduced tiny air bubbles.

The fourth type of inserted defect is cracks. At a depth of 10mm from the cylinder surface we inserted a shovel of width 4.5mm. The shovel is pushed radially to a depth of 50mm. After pulling out the shovel from the cylinder, we sealed the opening to simulate a sealed crack.

IV INSPECTION METHOD

1. The optical bench is set up according to the schematics in Figure 1, making sure that the optical path difference between the object light and the reference light is small. The angle between these two light beams is in the order of $20^{\circ}\sim45^{\circ}$. The intensity ratio between the object light and the reference light is in the order of $1:2\sim1:5$.
2. Set up the interference plate. The first exposure should be made after the plate is stabilized. The second exposure should be made after proper heat-stress loading is applied.

The durations of both exposures should be the same. When vacuum stress loading is used, the best way is to take the first exposure under vacuum condition; let the air in to the vacuum compartment, then take the second exposure under the reduced-vacuum condition.

3. After the two exposures, the interferometric plate should be processed in the dark room, using developing formula D-19 for 2-3 minutes, then fixing formula F-5 for 5 minutes. Then the plate will be ready for inspection.

The stress loading condition is determined by means of trial and error.

V EXPERIMENTAL RESULTS

First type, debond defect, heat-stress loaded.

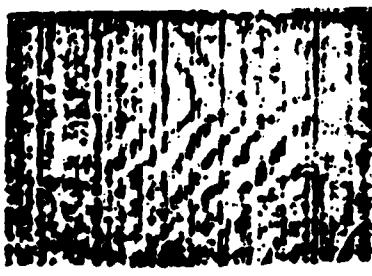


Figure 2, Defect width 2mm, length 30mm

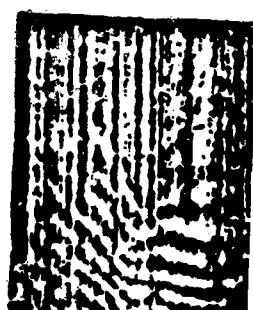


Figure 3, width 3mm, length 30mm

Second type, debond defect, heat-stress loaded.

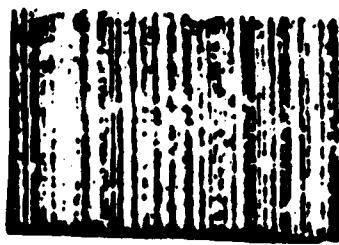


Fig 4, defect diameter 5mm, length 45mm



Fig.5, diameter 3mm, length 33mm



Fig 6, Defect diameter 1mm, length 27mm



Figure 7

Third type of defect, vacuum-stress loaded.



Fig 8 ϕ_2



Fig 9 $\phi_{1.5}$

Fourth type of defect, vacuum stressed.

The test results presented above are on one specific type of solid fuel cylinders. In 1981, we carried out a large number of tests with a different type of solid fuel cylinders. The results further indicated that this type of inspection technique not only can detect artificially inserted defects, it is also very effective in detecting the existence of tiny air bubbles. In addition to

this, we used soft X-ray to inspect the same samples and verified the reliability of this holographic non-destructive inspection technique. Figure 11 below, (vacuum stressed), shows the ϕ_3 debond in shield and also air bubbles.



Fig 10 Defect is 10mm away from cylinder surface, width 4.5mm, length 50mm

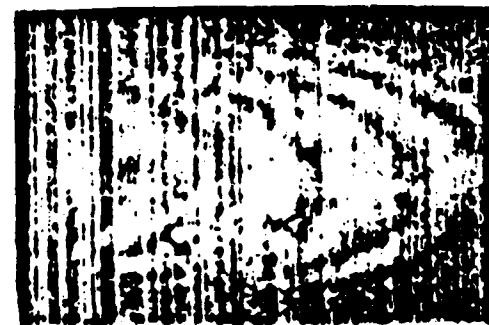


Fig 11

VI WHITE LIGHT RE-IMAGING OF NONDESTRUCTIVE INSPECTION

To simplify the re-imaging conditions of our experiments, we took pictures using imaging holographic and spectral holographic techniques. We were able to detect defects from the white light interference plate.



Fig 12 Imaging holography. Defect is interface debond ϕ_5 (heat stressed)

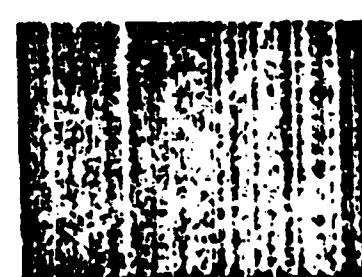


Fig 13 Spectral holography. Defect is interface debond ϕ_5 (heat stressed)

CONCLUSIONS

The results presented here are based on a large number of tests on two types of solid fuel cylinders. It is entirely practicable to employ the laser holographic non-destructive inspection method to detect debonds and small voids in this type of objects. This technique can also detect cracks of certain object. It can quantitatively estimate the extents of the debonds and the depths of the cracks.

We compared the two means of stress loading in these experiments. Vacuum stressing has the advantages that it is safer to operate, it is easier to accurately control the stress conditions, and it has a higher sensitivity than heat stressing. In the inspection of inflammable, explodable solid fuel type of material, the vacuum stress method is definitely superior to the heat stress method.

I express my gratitude for the guidance from Professor Hong Jing, Assistant Professor Yuan Shan-hung. Contributions from Comrades Gung Wan-jen and Chen Si-yuan are recognized.

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